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Performance of Crosses Between Six Inbred Lines of Swine

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INTRODUCTION

Much experimental work has been done on the effects of crossbreeding in swine. Most of this work has been reviewed by Robison (*8*)[2] and Lush and coworkers (*6*, *7*). The results of these and other workers have shown that crossbreds generally excel purebreds as producers of market hogs. Only in recent years have inbred lines become available for crossbreeding studies. Thus there is relatively little information concerning the performance of inbred line crosses as compared with that of breed crosses.

As the first step in determining the usefulness of inbred lines of swine for crossbreeding, the United States Department of Agriculture made the following swine importations: In 1934 from Denmark, 7 boars and 16 sows of the Danish Landrace breed and 2 boars and 4 sows of the Yorkshire breed; and in 1936 from England, 2 boars and 2 sows of the Large Black breed. Two inbred lines were formed from crosses made in 1934 between the Landrace and Duroc and between the Landrace and Poland China, two from crosses made in 1935 between the Landrace and Chester White and between the Yorkshire and Duroc, and one from a cross made in 1936 between the Landrace and a Large Black. In 1939, two new lines, one of which subsequently replaced the Yorkshire-Duroc line, were begun

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[2] Numbers in parentheses refer to Literature Cited, p. 13.

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by mating representatives of a Landrace × Hampshire cross made at Miles City, Mont., with stock from the Yorkshire-Duroc and Landrace-Duroc lines. All six inbred lines are at the Department's Agricultural Research Center, Beltsville, Md.

Although all the lines trace to crosses with the Landrace, the proportion of Landrace blood varies considerably between lines. The Yorkshire-Duroc-Landrace-Hampshire possesses about 5 percent; the Chester White-Landrace, about 14 percent; and the Landrace-Duroc, Landrace-Duroc-Hampshire, Landrace-Large Black, and Landrace-Poland China, about 75 percent each. By 1947, the average relationship among the 6 lines ranged from 0 to 25 percent and the average inbreeding of the lines from 23 to 42 percent, according to Wright's coefficients (*11*).

In 1947 and 1948, matings representing all the 30 possible reciprocal crosses between the 6 lines, as well as matings within each line, were made for fall litters. The primary purpose was to estimate the amount of heterosis in the inbred line crosses and to determine the effect of inbreeding on performance.

EXPERIMENTAL PROCEDURE

Each boar was mated to several females from each of the 6 lines. In 1947, 1 boar from a line was used; and in 1948, 2 boars. Only 1 boar sired litters in the 2 years. Most of the sows that farrowed in 1947 were retained for 1948 litters, but no sow was bred to have more than 1 litter in any one combination. In 1947, the 6 lines were represented by 16 litters and the 30 possible crosses by 82 litters. In 1948, the numbers were 19 and 102, respectively. The totals, therefore, were 35 inbred litters and 184 single-cross litters that could be used for this study.

The performance factors studied were litter size, litter weight, and individual pig weight at birth and at 21 and 56 days of age. In addition, for some of the pigs, weights at 98 and 140 days and average daily gain from 56 days to a final weight of about 225 pounds, as well as certain carcass measurements, were obtained. These pigs, in groups of four each, were self-fed under record-of-performance conditions in dry lots with concrete floors. To minimize the effect from differences between sows and boars, whenever possible two pairs of litter mates by different sires and distributed equally as to sex were fed out from each line and cross in each of the 2 years. Because most litters from a given type of mating differed rather widely in age, the pigs were grouped primarily according to age and only secondarily by type of breeding. Hence it was not possible to compare inbreds and crosses for feed requirements.

The method of analysis used in this study was to compare the mean performance of each pair of reciprocal crosses with the mean of its corresponding parent lines, treating the 15 mean differences for each year as the primary observations. Thus estimates of heterosis obtained should not be affected by differences in maternal influence and line differences which affect both inbreds and crosses. In order to obtain variance estimates equivalent to those based on individual observations, each difference was weighted by the reciprocal of its variance, as outlined by Yates (*12*), and shown in table 1.

TABLE 1.—*Sample of intrayear differences between means of pairs of reciprocal crosses* $\left(C=\frac{C_1+C_2}{2}\right)$ *and pairs of corresponding inbred parent lines* $\left(I=\frac{I_1+I_2}{2}\right)$ *in number of pigs per litter at birth*

Year	Parental lines [1]	Inbreds			Crosses			Mean difference $(C-I)=D$	Weight for inbreds w_i [2]	Weight for crosses w_c [2]	Weight for mean difference w_d [3]
		Litters		Mean pigs per litter (I)	Litters		Mean pigs per litter (C)				
		n_{i1}	n_{i2}		n_{c1}	n_{c2}					
		Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*			
1947	CW-L×L-D-H	1	3	9.00	3	2	9.50	0.50	0.98	1.57	0.60
1948	L-D×L-LB	4	3	10.04	4	4	11.50	1.46	2.25	2.62	1.21
1947, total for 6 lines (15 differences)		16		8.09	82		9.73	1.64			12.47
1948, total for 6 lines (15 differences)		19		9.41	102		10.51	1.10			15.43
Grand total (30 differences)		35		8.82	184		10.16	1.34			27.90

[1] CW=Chester White, D=Duroc, H=Hampshire, L=Landrace, and LB=Large Black.

[2] $w_i=\frac{n_{i1}\times n_{i2}}{n_{i1}+n_{i2}}\times\frac{4(\bar{k}_i+\bar{k}_c)}{l\bar{k}}$ and $w_c=\frac{n_{c1}\times n_{c2}}{n_{c1}+n_{c2}}\times\frac{4(\bar{k}_i+\bar{k}_c)}{l\bar{k}}$,

where n_{i1}, n_{i2}, and n_{c1}, n_{c2}=number of observations in a given year for a pair of inbreds and reciprocal crosses, respectively,

$\bar{k}_i$=average number of observations per inbred line and year,

$\bar{k}_c$=average number of observations per cross and year,

$\bar{k}$=average number of observations per line and cross subclass and year,

l=number of inbred lines.

[3] $w_d=\frac{w_i\times w_c}{w_i+w_c}$.

Analysis-of-variance methods, as shown in table 2 for litter size, were used to test the significance of the average difference between crosses and inbreds, the variation in the intrayear differences among the various pairs of crosses and inbreds, and the variation in the differences between the 2 years. To remove the effect from intrayear differences in age of dam, inbreeding of dam, and inbreeding of litter, the interactions of heterosis × crosses, of heterosis × years, and of heterosis × crosses × years were adjusted by multiple covariance analyses by using the partial regressions within types of matings. The mean squares for heterosis were adjusted for differences in age and inbreeding of dam, but not for differences in inbreeding of litter. The formula for this was previously given by Dickerson and coworkers (4). The mean squares for heterosis were tested against the variance obtained by pooling the three interactions, except where there was evidence of significant interaction of heterosis × crosses or of heterosis × years. In such cases a composite test was used by following an approximation suggested by Satterthwaite (9), as outlined by Cochran and Cox (2).

TABLE 2.—*Variance of intrayear differences between means of pairs of crosses and of pairs of corresponding inbred lines in number of pigs per litter at birth*

Source of variation	Observed		Adjusted [1]	
	Degrees of freedom	Mean square [2]	Degrees of freedom	Mean square [2]
Mean heterosis	1	50. 2**	1	42. 3**
Heterosis × crosses	14	2. 9	14	2. 6
Heterosis × years	1	2. 1	1	2. 4
Heterosis × crosses × years	14	3. 0	14	2. 7

[1] For multiple regression on age and inbreeding of dam and on inbreeding of litters, except heterosis not adjusted for mean difference in inbreeding of litters.
[2] ** P $\leq$0.01, highly significant.

The mean difference between crosses and inbreds in litter size at birth is highly significant both before and after adjustment for intrayear differences in age and inbreeding of dam. The interactions of heterosis × crosses and of heterosis × years are both insignificant when compared with the triple interaction. Therefore, most if not all of the crosses were superior to their corresponding inbred parents, and this superiority did not vary appreciably between years or between crosses.

VIABILITY AND RATE OF GROWTH

Differences Between Crosses and Inbreds

A summary of the results on viability and rate of growth of crosses and inbreds is given in table 3. Representative animals of the inbred lines are shown in figure 1; of the crosses, in figure 2. Although collectively crosses and inbreds averaged about the same in age and

inbreeding of dams, there were a few pairs whose dams differed by larger amounts than are indicated by the average differences. To minimize any bias due to these differences, the differences for litter size and litter weight, as well as those for pig weight, were adjusted to a mean difference of zero in age and inbreeding of dams.

Crosses exceeded inbreds in number of pigs per litter at birth and at 21 and 56 days of age. These differences were highly significant. They became slightly smaller after adjustment, but they remained highly significant at all three ages. Thus both prenatal and postnatal viability in crosses were higher than in inbreds, since there is no reason to think that the two groups of dams differed in reproductive efficiency. Crosses differed little from inbreds in pig weight at birth and at 21 days of age, but crosses were significantly heavier at 56 days of age. In litter weight, crosses were also superior to inbreds, partly because of the larger number of pigs in the line-cross litters and partly because crosses tended to have heavier individual pig weights.

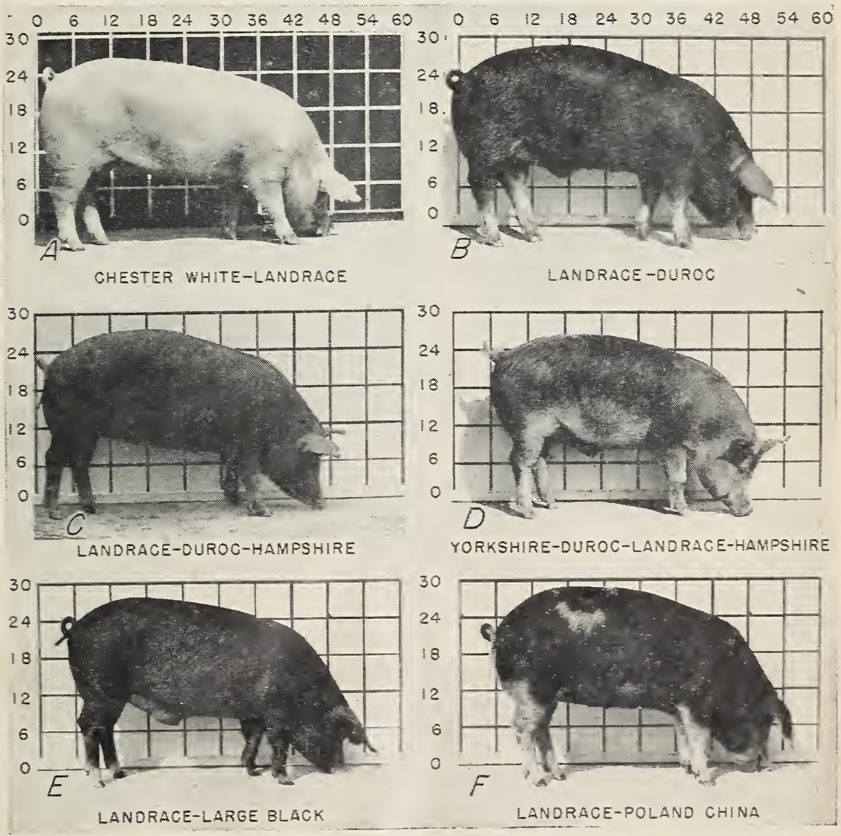

FIGURE 1.—Representative animals of the 6 inbred lines at 6 months of age weighing approximately 225 pounds each.

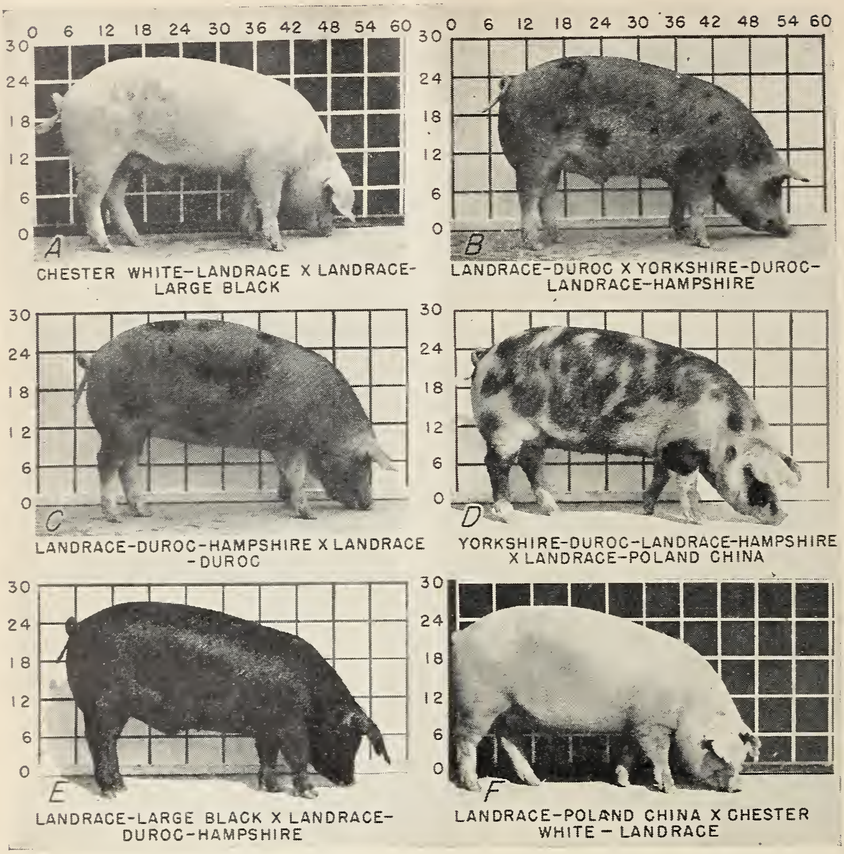

FIGURE 2.—A sample of crossbred animals at 6 months of age weighing approximately 225 pounds each.

The results of the feeding trials are also summarized in table 3. Although 8 pigs were to be fed out from each line and cross, 3 of the crosses were represented by only 7 pigs each, resulting in a total of 48 inbred and 237 line-cross pigs for which weights were obtained after weaning. The inbreds were selected from 22 litters and the crosses from 118 litters; about two-thirds of the litters farrowed in each group, therefore, were represented in the feeding trials.

The inbreds included a larger proportion of the heavier pigs than did the crosses but, even so, crosses averaged heavier in initial weight than did the inbreds. At 98 days and 140 days crosses were significantly heavier than inbreds. After adjusting to a mean difference of zero in age and inbreeding of dams, the crosses were still significantly heavier. However, the fact that the differences decreased somewhat indicates that a part of the advantage in rate of gain exhibited by the crosses was due to variation in age and inbreeding of dams. In daily gain from 56 days to a final weight of about 225 pounds, crosses were significantly superior to inbreds. The difference became slightly smaller after adjustment to a difference of zero in initial weight and

TABLE 3.—*Intrayear comparisons of crosses and inbreds from birth to weaning and from weaning to a final weight of about 225 pounds*

Observation	Inbreds (I)	Crosses (C)	Difference (C–I)[1]		Decline per 10 percent inbreeding of litter
			Observed[2]	Adjusted[2]	
Birth to weaning:					
Litters .... number	35	184			
Inbreeding of litters .... percent	28.4	4.3	−21.1	−21.1	
Inbreeding of dams .... do	25.5	25.2	−.3	0	
Age of dams .... months	20.1	20.9	.8	0	
Litter size at—					
Birth .... number pigs	8.8	10.2	1.1**	1.2**	0.51
21 days .... do	6.2	8.0	1.8**	1.7**	.70
56 days .... do	5.9	7.7	1.8**	1.7**	.71
Pig weight at—					
Birth .... pounds	2.64	2.59	−.05	−.05	
21 days .... do	10.1	10.4	.3	.3	.12
56 days .... do	26.7	29.3	2.6**	2.7**	1.1
Litter weight at—					
Birth .... do	23.3	26.1	2.8**	2.4*	1.0
21 days .... do	63.6	82.8	19.2**	17.9**	7.4
56 days .... do	159.4	226.8	67.4**	63.7**	26.5
Weaning to 225 pounds:					
Pigs fed .... number	48	237			
Inbreeding of pigs .... percent	30.2	3.9	−26.3	−26.3	
Pig weight at—					
56 days .... pounds	30.2	31.9	1.7	0	
98 days .... do	76.6	83.6	7.0**	6.6**	2.5
140 days .... do	148.5	158.5	10.0**	9.3**	3.5
Total gain .... do	194.1	191.8	−2.3	0	
Daily gain .... do	1.58	1.65	.07*	.06*	.024

[1] Differences adjusted to a mean difference of zero in age and inbreeding of dams, except difference in daily gain adjusted to zero difference in initial weight and total gain.

[2] $^*P \leqq 0.05$, significant; $^{**}P \leqq 0.01$, highly significant.

total gain but remained statistically significant. If the crosses had included as selected a sample of pigs as did the inbreds, their advantage in rate of growth would probably have been even more pronounced.

Genetic Relationship Between Lines and Heterosis Effect

The average genetic relationship among the 6 lines was calculated to be 7 percent. In order to measure its influence on heterosis, the performance of each pair of reciprocal crosses was computed as a percentage of the mean performance of its corresponding parent lines. The results are summarized in table 4. The correlations and regressions of the heterosis effect on the relationship between lines are also shown in the table. All the correlations were negative except the one for litter size at birth, which was positive but small and not statistically significant. The correlations for litter weight at 21 and 56 days, for pig weight at 21, 98, and 140 days, and for daily gain were significant, indicating that differences in degree of relationship among the 6 lines had a real influence on the amount of heterosis exhibited by these characters.

The fact that the correlation for weight at 140 days was higher than those at earlier ages agrees with results obtained by Baker and coworkers (*1*) and Krider and coworkers (*5*), who showed that the heritability of weight increases with increasing age. In fact, the size of the correlation for the 140-day weight indicates that the amount of heterosis in weight at this age could have been predicted fairly accurately from the degree of relationship among the lines crossed. As shown by the regression coefficients in table 4, the reduction in heterosis for weight at 140 days amounts to about 4 percent for an increase of 10 percent in relationship between lines.

Estimates of the average advantage that crosses would have exhibited over inbreds if none of the parent lines had been interrelated are given in the lower part of table 4. The differences between these estimates and those unadjusted for the average relationship between lines clearly point to the conclusion that the lower the relationship between inbred lines, the higher, in general, is the heterosis effect.

Since different breeds probably are no more closely related than the inbred lines used in this study, these estimates may be compared with those based on crosses between breeds. The advantage found in this study for crosses in litter size at weaning—35 percent—is somewhat higher than that for Landrace × Poland China crossbreds over purebred Poland Chinas reported by Lush and coworkers (*7*)—approximately 0.7 pig, the equivalent of about 15 percent. It is also higher than that for Poland China × Duroc and Duroc × Chester White crossbreds over the average of these breeds reported by Winters and coworkers (*10*)—0.3 pig, the equivalent of about 5 percent. Lush and coworkers, on the other hand, reported a greater advantage for their crosses in rate of growth—0.21 pound average daily gain from weaning to market weight, the equivalent of about 16 percent over that of the 5 percent estimated for the present crosses. These differences in results may be due largely to variation in genetic diversity between the particular lines and breeds crossed, rather than to a general difference in heterosis obtained from breed crosses as compared with inbred line crosses. In this connection, a part of the greater advantage in growth rate obtained for breed crosses, as re-

TABLE 4.—*Estimates of heterosis effect in pairs of reciprocal crosses (calculated as percentage of means of inbred parents)*[1] *according to genetic relationship between pairs of inbreds*

Parental lines [2]	Relationship between pairs of lines	Litter size at—			Litter weight at—			Pig weight at—					Daily gain in feed lot
		Birth	21 days	56 days	Birth	21 days	56 days	Birth	21 days	56 days	98 days	140 days	
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
CW-L × Y-D-L-H	0.000	100	133	137	103	132	149	106	101	110	108	108	104
Y-D-L-H × L-LB	.000	110	120	128	115	135	158	105	115	126	112	106	102
Y-D-L-H × L-PC	.000	128	140	140	131	151	158	103	111	113	103	106	106
CW-L × L-D	.011	112	140	141	106	149	158	94	106	113	122	114	106
CW-L × L-PC	.013	136	158	153	124	159	170	93	104	110	114	110	108
CW-L × L-LB	.018	115	127	135	104	124	149	91	100	114	114	109	104
L-D × Y-D-L-H	.018	101	128	129	105	137	143	104	108	110	118	110	104
CW-L × L-D-H	.020	106	134	136	102	129	135	96	97	101	106	108	106
L-D-H × Y-D-L-H	.032	100	109	110	102	116	122	104	108	112	111	107	105
L-D-H × L-PC	.109	112	97	98	97	95	103	88	99	106	99	102	105
L-D-H × L-LB	.121	105	113	117	101	116	130	98	104	116	106	105	104
L-LB × L-PC	.123	141	139	142	127	127	148	92	94	104	102	103	105
L-D × L-PC	.136	140	166	164	135	153	169	97	93	101	105	104	107
L-D × L-LB	.142	117	123	126	114	122	139	98	103	116	106	103	101
L-D × L-D-H	.248	100	108	102	95	104	102	96	98	101	102	98	99
Mean	.070	114	127	129	110	128	140	98	103	110	108	106	104
Correlations between heterosis effect and relationship between lines (13 degrees of freedom) [3]		0.06	−0.28	−0.37	−0.10	−0.53*	−0.54*	−0.31	−0.55*	−0.45	−0.61*	−0.82**	−0.53*
Regression of heterosis effect on relationship between lines [3]		0.11	−0.69	−0.88	−0.02	−1.29*	−1.51*	−0.25	−0.45*	−0.40	−0.53*	−0.43**	−0.16*
Heterosis effect adjusted to zero relationship between lines		113	132	135	110	137	150	100	106	113	112	109	105

[1] After adjusting performance of inbreds to same mean age of dams and inbreeding of dams as crosses, except daily gain adjusted for differences in initial weight and total gain.
[2] CW=Chester White; D=Duroc; H=Hampshire; L=Landrace; LB=Large Black; PC=Poland China; Y=Yorkshire.
[3] $^*P \leqq 0.05$, significant; $^{**}P \leqq 0.01$, highly significant.

ported by Lush and coworkers, may have been due to the fact that their estimate presumably included the effect of differences that were evident at weaning time, whereas the estimate of 5 percent obtained in the present study reflects only the heterosis effect that became evident after weaning.

The extent to which the various pairs of lines varied in their response to crossing is shown in figure 3. On the whole, the crosses exhibited a proportionately greater advantage in litter size or viability than in

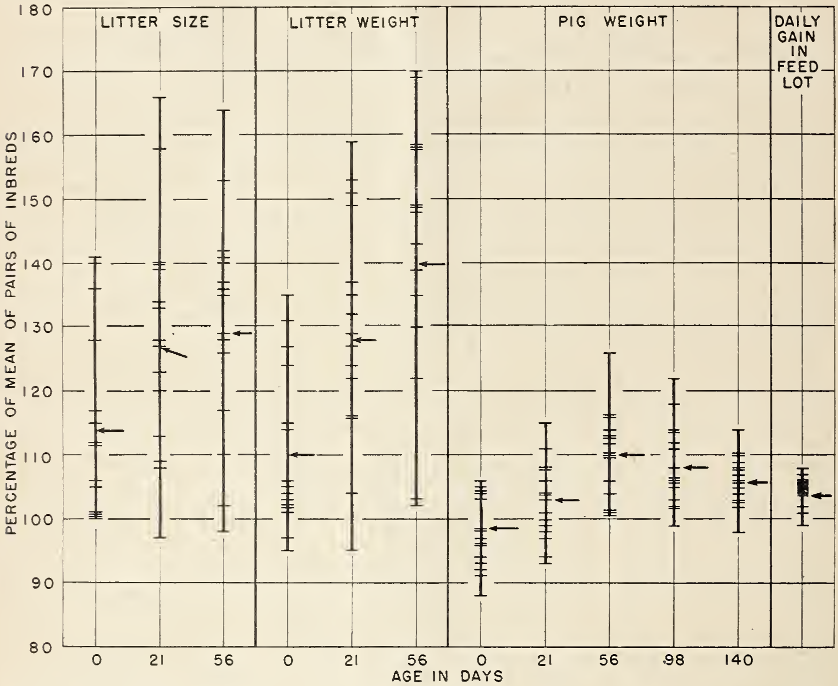

FIGURE 3.—Performance of 15 pairs of reciprocal crosses calculated as percentage of means of corresponding inbreds. (Arrows indicate average for all crosses.)

rate of growth. These results agree with those of Lush and coworkers (*7*) and Dickerson and coworkers (*4*).

EFFECT OF INBREEDING

Estimates of the average decline in performance for each 10 percent increase in inbreeding of litters are given in table 3. These estimates were obtained by the same method as that used by Dickerson and coworkers (*4*) in their study of hybrid vigor in crosses among inbred lines of Poland Chinas. Since the degree of heterozygosity in outbred Poland Chinas would not be so high as that in the crossbred foundation stock of the present lines and their crosses, one might expect estimates of the effect of inbreeding reported by these workers to be somewhat smaller than those found in the present study, except where the average level of heterozygosity did not differ appreciably between the two sets of foundation stock. Actually, the declines of 0.26,

0.35, and 0.37 pig, which Dickerson and coworkers found for litter size at birth and at 21 and 56 days of age, respectively, were about half those found in this study. Their estimate of 6.8 pounds for decline in weight at 154 days, on the other hand, agrees fairly well with the decline of 3.5 pounds for weight at 140 days, since this corresponds to a decline of about 5.7 pounds in terms of weight at 154 days. The present findings are also comparable with estimates of intrayear regressions on inbreeding reported by other workers. For example, Comstock and Winters (*3*) estimated the decline in daily gain from weaning to 200 pounds per 10 percent increase in inbreeding as 0.027 pound. This agrees rather closely with the 0.024-pound decline found in the present study.

CARCASS YIELDS AND DIMENSIONS

Carcass data were obtained on all the inbred pigs and on all but three of the line-cross pigs that were fed to market weight. The results for the two groups are summarized in table 5. They averaged about the same in live weight at slaughter. Crosses exceeded inbreds in dressing percentage and in length of carcass, but the differences were not significant. The inbreds had a slightly higher yield of the five primal cuts and also of lean meat in hams, but these differences also were too small to be significant. On the other hand, crosses exceeded inbreds significantly in both thickness of back fat and in yield of fat cuts. Although the crosses were fatter than the inbreds, the fact that they differed little from the inbreds in yield of the leaner cuts suggests that their additional fat was largely responsible for their higher dressing percentage.

TABLE 5.—*Intrayear comparisons of crosses and inbreds in various carcass characteristics*

Observation	Inbreds	Crosses	Difference [1] between crosses and inbreds
Pigs____number__	48	234	______________
Inbreeding of pigs____percent__	30. 2	4. 3	—25. 9
Live weight at slaughter____pounds__	211. 1	211. 0	—. 1
Yield as percentage of weight at time of slaughter:			
Chilled carcass____percent__	79. 7	80. 1	. 4
Preferred cuts:			
Trimmed ham____do____	15. 0	15. 1	. 1
Trimmed loin____do____	12. 0	11. 9	—. 1
Trimmed belly____do____	10. 5	10. 6	. 1
Picnic shoulder____do____	7. 3	7. 2	—. 1
Shoulder butt____do____	4. 9	4. 7	—. 2
Total____do____	49. 7	49. 5	. 2
Fat cuts (back fat, leaf fat, cutting fat, plate)____percent__	14. 6	15. 3	. 7**
Lean meat in ham____do____	8. 5	8. 4	—. 1
Length (aitchbone to first rib) centimeters__	78. 6	78. 8	. 2
Back fat thickness (average of five locations)____centimeters__	4. 24	4. 39	. 15**

[1] **$P \leq 0.01$, highly significant.

SUMMARY

To determine the effect of crossing inbred lines of swine for the production of market hogs, single crosses between 6 inbred lines of swine were compared with their parental lines. The inbred lines were developed at the United States Agricultural Research Center at Beltsville, Md., from crosses involving 7 breeds, namely, Danish Landrace, Danish Yorkshire, English Large Black, Chester White, Duroc, Hampshire, and Poland China.

The data came from litters farrowed in 1947 and 1948 and included 35 inbred litters and 184 single-cross litters, representing all 30 possible reciprocal crosses. The average genetic relationship among the 6 lines was 7 percent. Inbreeding of litters averaged 28 percent for inbreds and 4 percent for crosses. For inbreeding of dam, the averages were 26 and 25 percent, respectively; for age of dam, 20 and 21 months. In analyzing the data, mean intrayear differences between pairs of reciprocal crosses and corresponding lines were used as the primary observations. Performance of inbreds and crosses was adjusted to the same age and inbreeding of dams.

Crosses exceeded inbreds by 1.2 pigs per litter, or 14 percent, at birth; by 1.7 pigs, or 27 percent, at 21 days; and by 1.7 pigs, or 29 percent, at 56 days. Therefore, both prenatal and postnatal viability were higher among crosses than among inbreds. In litter weight, crosses exceeded inbreds by 2.4 pounds, or 10 percent, at birth; by 17.9 pounds, or 28 percent, at 21 days; and by 64 pounds, or 40 percent, at weaning. In individual pig weight, differences in favor of crosses were 0.3 pound, or 3 percent, at 21 days; 2.7 pounds, or 10 percent, at 56 days; 6.6 pounds, or 8 percent, at 98 days; and 9.3 pounds, or 6 percent, at 140 days. Carcass data showed that crosses had a slightly higher dressing percentage, a slightly lower yield of lean cuts, and more fat than did inbreds.

When the performance of the crosses was adjusted to correspond to that of crosses between nonrelated inbred lines, the advantages in their favor were generally higher than were indicated by the actual results. These results agree with the view held by most workers that the lower the relationship between inbred lines, the higher, in general, is the performance of crosses between them. The results also agree with published data in that the crosses exhibited a proportionately greater advantage in litter size or viability than in rate of growth.

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